

Bone functions and the requirements for bone grafts and substitutes in the orofacial region

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[Received 21 December 2005; Accepted 8 February 2006]

Bone is the largest calcium storage, has distinctive plasticity and adaptability and is part of the supporting tissue. An adequate composition is thus necessary. The bone matrix consists of organic and anorganic structures. Osteoblasts, osteoclasts and osteocytes are responsible for bone formation, resorption and metabolism. The periosteum, endosteum and bone tissue are a functional unit and provide protection, nutrition and growth. Bone is subject to continuous remodelling.

Key words: bone composition, function, metabolism, remodelling

INTRODUCTION

The orofacial or stomatognathic system with its components forms a functional circle representing a biocybernetic system with bone playing a key role. The structure of the osseous viscerocranium is targeted to withstand and divert the chewing pressure [5]. This requires a functional composition which is maintained even after osseointegration of bone graft substitutes. The periods of function and inactivity occurring in the jaw bones are more clearly noticeable than in any other bone of the body. Continuous remodelling guarantees adaptation to the forces that arise [3].

BONE FUNCTIONS

Supportive function

The bones make up the skeleton which bears the body's weight. Additionally, the skeleton provides the origin and attachment of the muscles. Owing to its biological plasticity, bone is capable of adaptation to stress.

Protective function

The cranial bones protect the central nervous system, the sense organs, and the bone marrow.

Development of masticatory pressure pillars

The development of masticatory pressure pillars in the viscerocranium diverts the chewing pressure and the trajectorial structure of the mandible (Fig. 1).

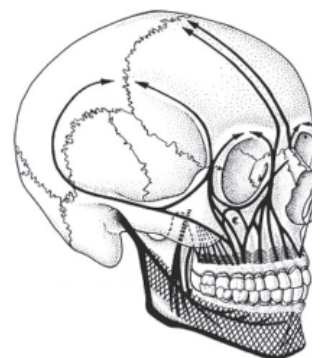


Figure 1. Functional structure of the viscerocranium [5].

Calcium storage

About 99% of the body's calcium is stored in the skeleton, including the cranial bones. The stored calcium is mobilised when blood calcium concentration declines. Calcium is mainly released from hydroxyapatite crystals in the spongy substance.

Hormone and vitamin metabolism

Bone is connected to hormone and vitamin metabolism. The osteoblasts possess receptors for parathyroid hormone, vitamin D3, cytokines and growth factors. They produce factors that increase osteoclast proliferation and differentiation. Calcitonin exerts a receptor-mediated inhibiting effect on osteoclast activity. Androgens as well as oestrogens generally stimulate the building of bone substance and accelerate epiphyseal gap and suture closure.

BONE COMPOSITION

Bone is a specific connective tissue, which mainly consists of the extracellular substance/bone matrix, cells, vessels, and nerves.

Bone matrix

The bone matrix consists of anorganic and organic material [4]. The anorganic material, which determines bone stiffness, constitutes about half of the matrix. The major part (50%) is composed of calcium and phosphate in the form of hydroxyapatite crystals. Additionally, non-crystalline calcium phosphate, citrate, bicarbonate and, further, magnesium, kalium and sodium salts are found. The apatite crystals are surrounded by matrix substance and lie along the collagen fibrils. A "hydration cover" facilitates ion exchange between crystal and body fluids. The non-calcified organic matrix is referred to as osteoid and provides the body's elasticity. It consists mainly of collagen.

Bone cells

Cells are indispensable for osseointegration.

Osteoblasts are located exclusively at the surface of spongy trabecles and synthesise and secrete Collagen I, proteoglycans and glycoproteins. As their activity diminishes, the cells become increasingly flatter and form processes. The matrix proteins produced are released towards the surface of the existing bone matrix. The organic material enabling bone elasticity constitutes about 20%. Finally, water amounts to about 10% of the matrix substance.

Osteoclasts are multi-nucleate, large mobile cells, which resorb mineralised bone and stem from the mononuclear phagocyte system. One surface of re-

sorbing osteoclasts faces the mineralised bone tissue. The surface periphery is closely connected to the matrix by a sealing zone. The area surrounded by this zone displays numerous folds (a "ruffled border"). Between the "ruffled border" and the bone matrix there is an extracellular space, the so-called "resorption lacuna" where bone resorption occurs. The osteoclast secretes H^+ ions to the lacuna by means of a vacuolar ATPase located in the folded membrane, and the matrix minerals are dissolved in the acid milieu. The release of lysosomal enzymes leads to decomposition of the collagen fibrils.

Osteocytes develop from osteoblasts and represent the metabolic centres of the bone. Their cell bodies are located in the lacunae. With their processes they are interconnected by gap junctions composed of arrays of small channels. The processes permit intercellular substance transport. An exchange of compounds between osteocytes, mineralised matrix and blood vessel also occurs in the gap system between cells and calcified bone matrix. The cells respond to mechanical stress exerted on the bone and sustain the extracellular matrix. After their death the matrix undergoes resorption.

Periosteum and endosteum

The main functions of these are protection and nutrition as well as the continuing supply of osteoblasts for thickness growth and successful defect repair. The outer layer of the periosteum, the *stratum fibrosum*, consists of fibroblasts, collagenous and elastic fibres. Sharpey's fibres are bundles of collagenous fibres connecting the periosteum with the bone substance. The inner layer, the *stratum germinativum*, is formed by divisible cells ("lining cells") which can differentiate into osteoblasts. The stem cells play an important role for bone growth and repair. The endosteum fills the inner cavities of the bone, is thinner than the periosteum, and consists of progenitor cells and only a small amount of connective tissue.

Bone types

According to the array of osteocytes and collagen fibres, reticulated bone and lamellar bone are distinguished.

Reticulated bone (also "primary bone") is found only during bone development and repair processes, and, therefore, also in osseointegration. Its mineral content and radiodensity is lower. The collagen fibrils run irregularly. This type of bone is replaced, except in the suture and alveolar areas, by lamellary bone.

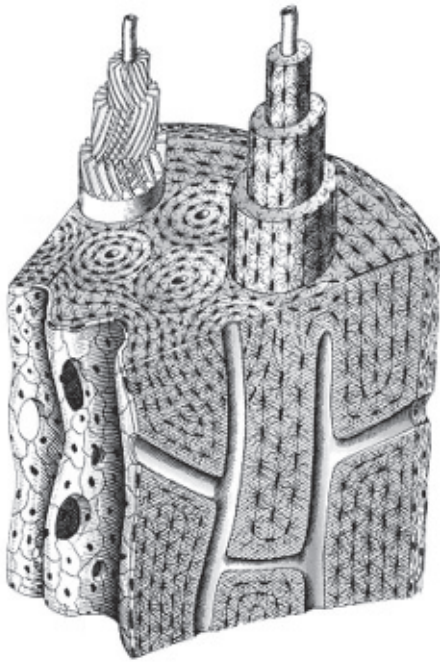


Figure 2. Bone lamellae [2].

Within **lamellary bone** (Fig. 2) the collagen fibres and the other matrix components form lamellae of 3–7 μm thickness, which are arrayed in concentric layers around a central channel (the Haversian canal). This structure is referred to as the “Haversian system” or “osteon”. The cell bodies of the osteocytes are located between the lamellae. Each channel contains nutritive vessels, nerve fibres, and loose connective tissue. The canals communicate with the bone marrow cavity, the periosteum and with each other (by Volkmann’s canals, which also lead outward). The channel system reflects a complex and delicate microcirculation [1]. Each osteon is surrounded by mineralised matrix with few collagen fibres (cementum). Immediately beneath the periosteum and around the marrow cavity lie general lamellae, more outer and fewer inner. Between the outer and inner general lamellae are located the so-called osteons and the often irregularly shaped intermediate lamellae. The latter are residual lamellae of a Haversian system which has been degraded during a remodelling process.

Substantia compacta, Substantia spongiosa of the cranial bones. The outer compact bone layer is referred to as the *substantia compacta*, the inner layer, which possesses numerous interconnected cavities, as the *substantia spongiosa*. The latter represents a spongy trabecular framework. However, both structures show lamellary bone composition.

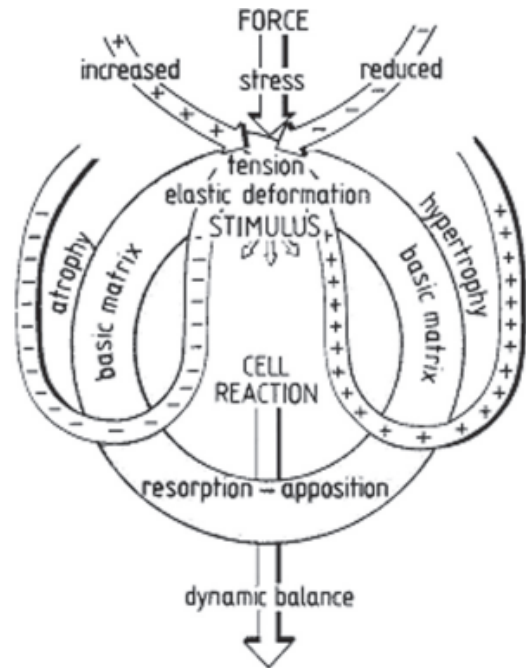


Figure 3. Functional structure of bone and dynamic equilibrium [3].

BONE BEHAVIOUR

Bone shape and composition are adjusted to its mechanical function. The structure reflects trajectorial architecture and conforms to tension and strain trajectories. Bone substance is arranged in such a way that the best possible absorption and transmission is achieved with minimum expense of material in the loaded area. The trajectorial construction, of the mandible for example, permits selective material usage in the loaded area. This lightweight construction saves muscular strength for motor activity. Bone morphology is genetically determined and is modified by external influences through differentiation. Bone is solid by its anorganic components and elastic by its organic components. Thus bone substance is in a dynamic equilibrium of adaptation [3]. Figure 3 shows the oscillation between atrophy and hypertrophy, resorption and apposition.

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